43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
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ACOUSTIC INSTABILITY IN PILOT-OPERATED PRESSURE SAFETY VALVES

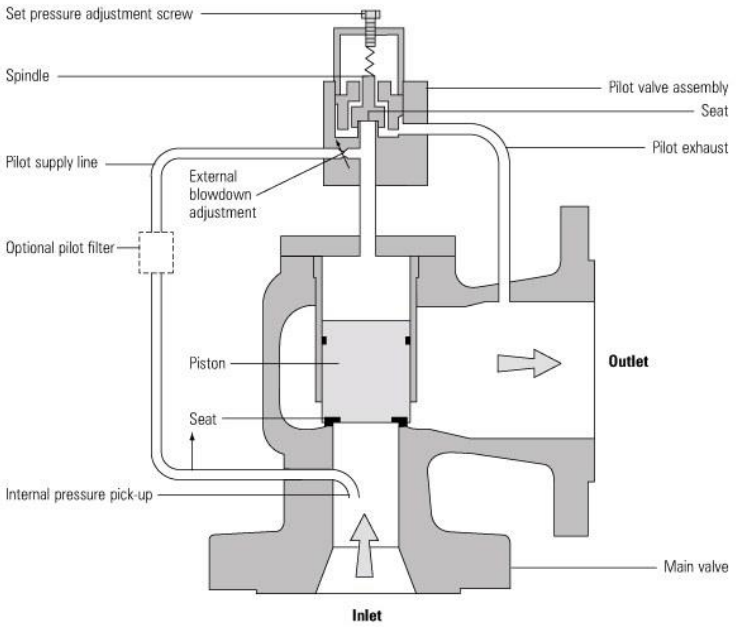
SwRI

TEXAS A&M UNIVERSITY

TEES
TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

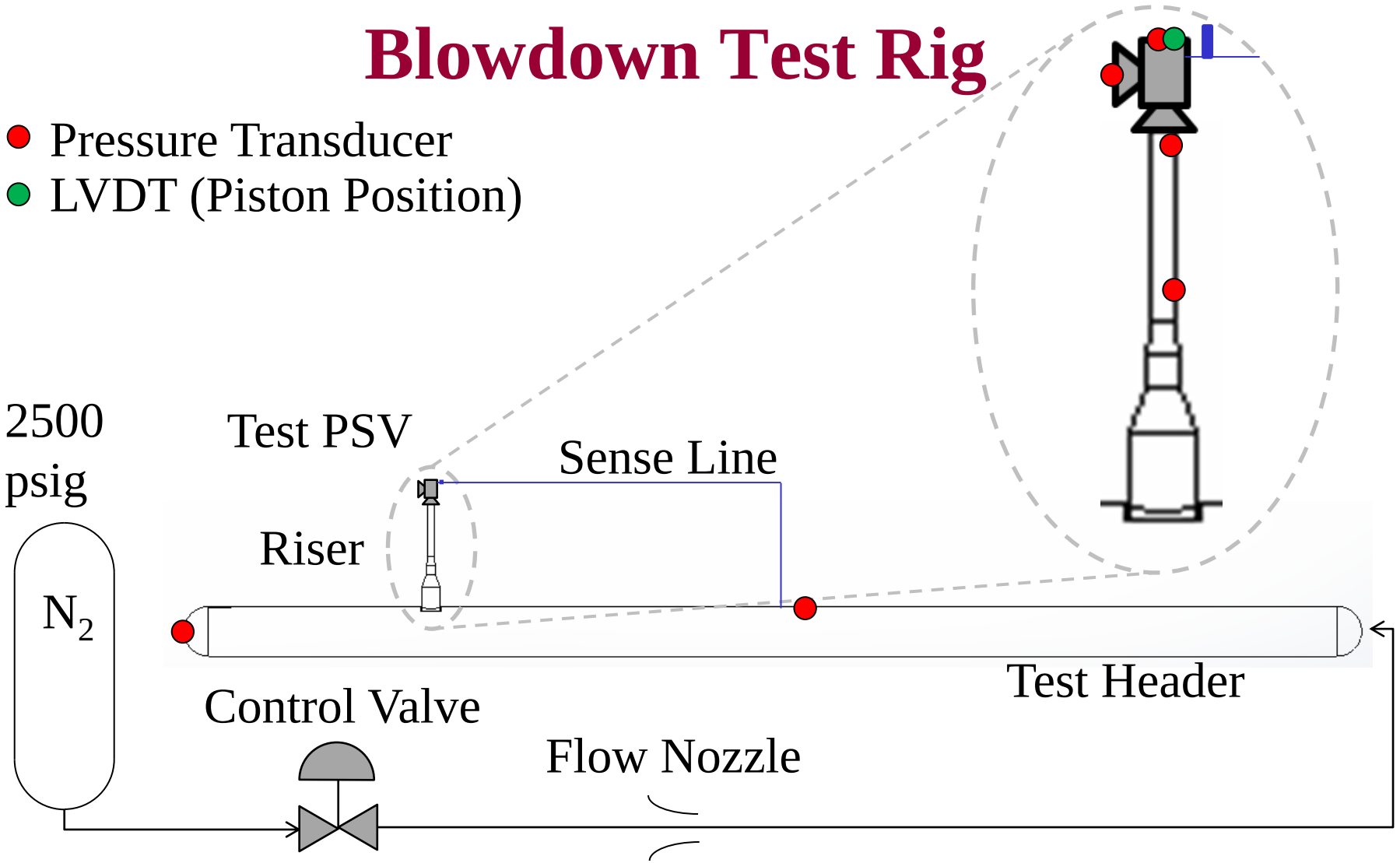
Background

- An offshore facility experienced a PSV lift and failure to reseal.
- Inspection and analysis of the valves showed that the valve seats and stop bolts were significantly damaged from apparent repetitive piston impacts
- Testing in the PSV manufacturer's blowdown test rig successfully replicated damaging PSV piston oscillations during blowdown, but physical cause of oscillations remained unknown.



Blowdown Test Rig

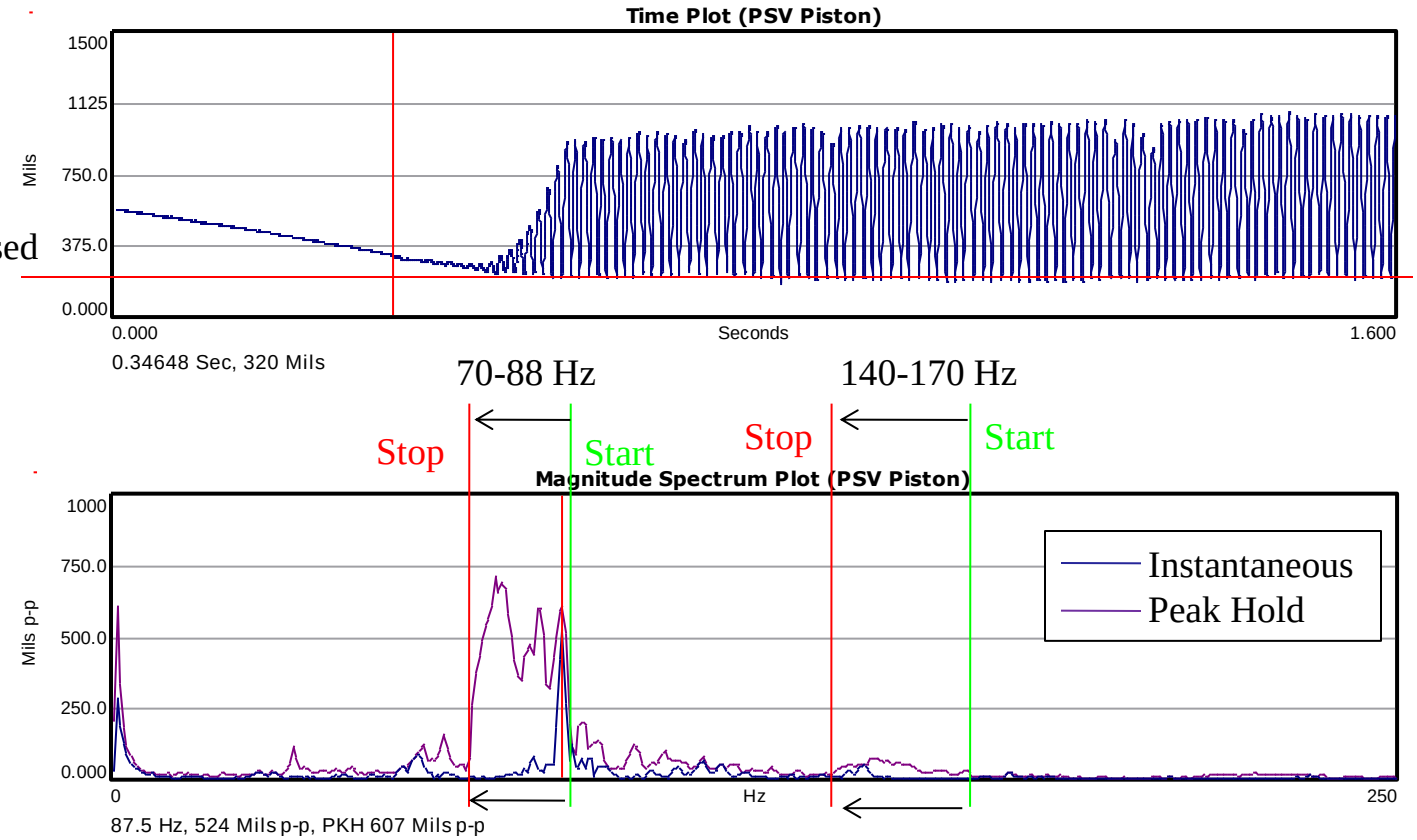
- Pressure Transducer
- LVDT (Piston Position)



Note: Performed tests both with and without riser

Blowdown Test Results – Piston Motion

Piston Closed Position



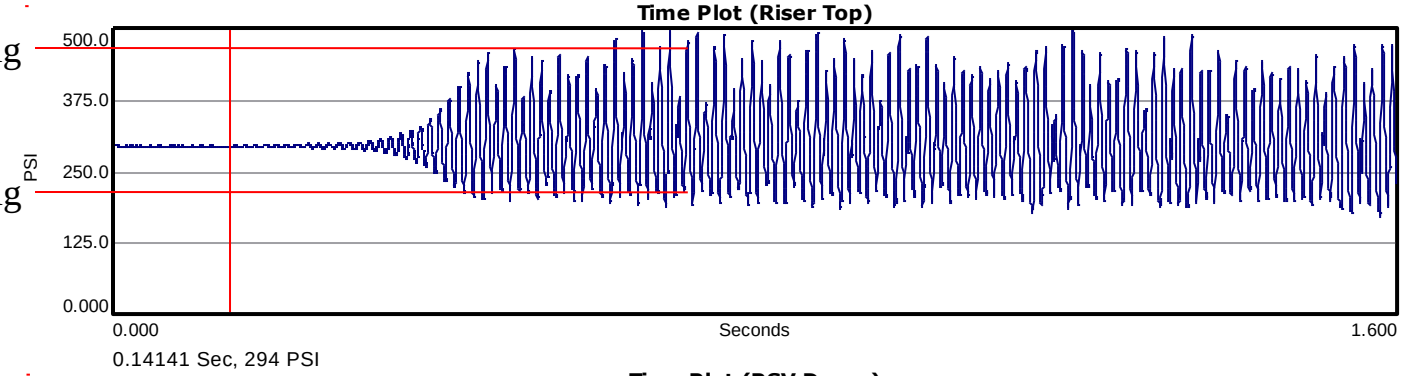
Piston oscillation begins at 88 Hz and lowers in frequency to 70 Hz as header pressure/temperature drops. Minor 2x oscillation is also observed.

Blowdown Test Results – Pressures

450 psig

Riser Top

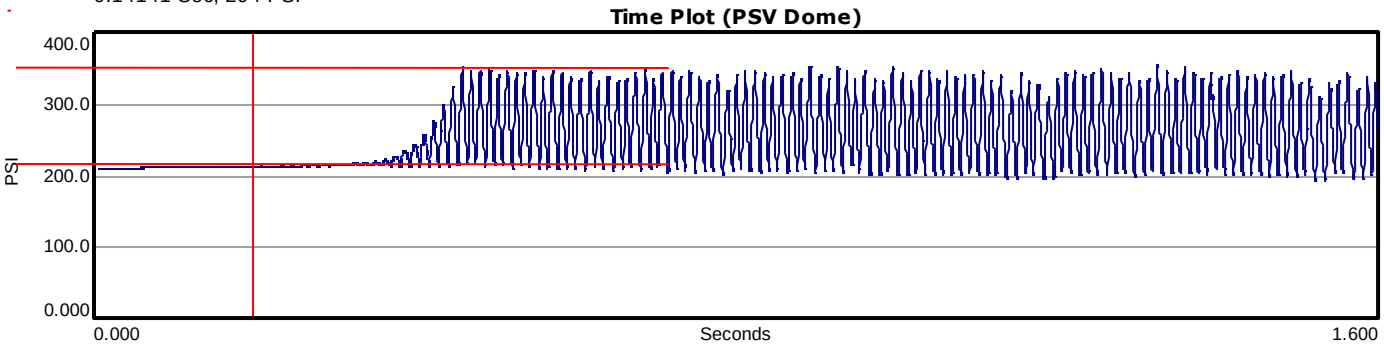
210 psig



350 psig

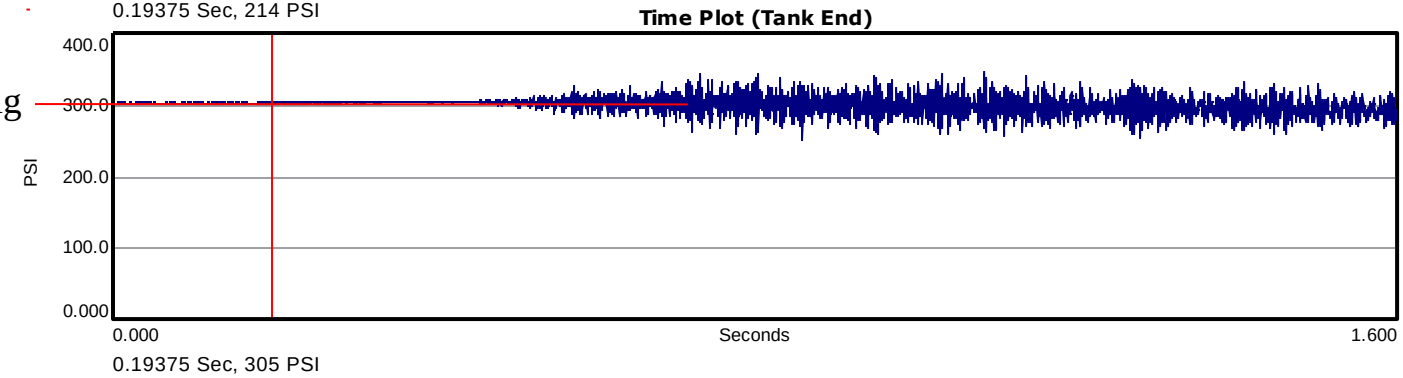
210 psig

PSV Dome



300 psig

Tank End

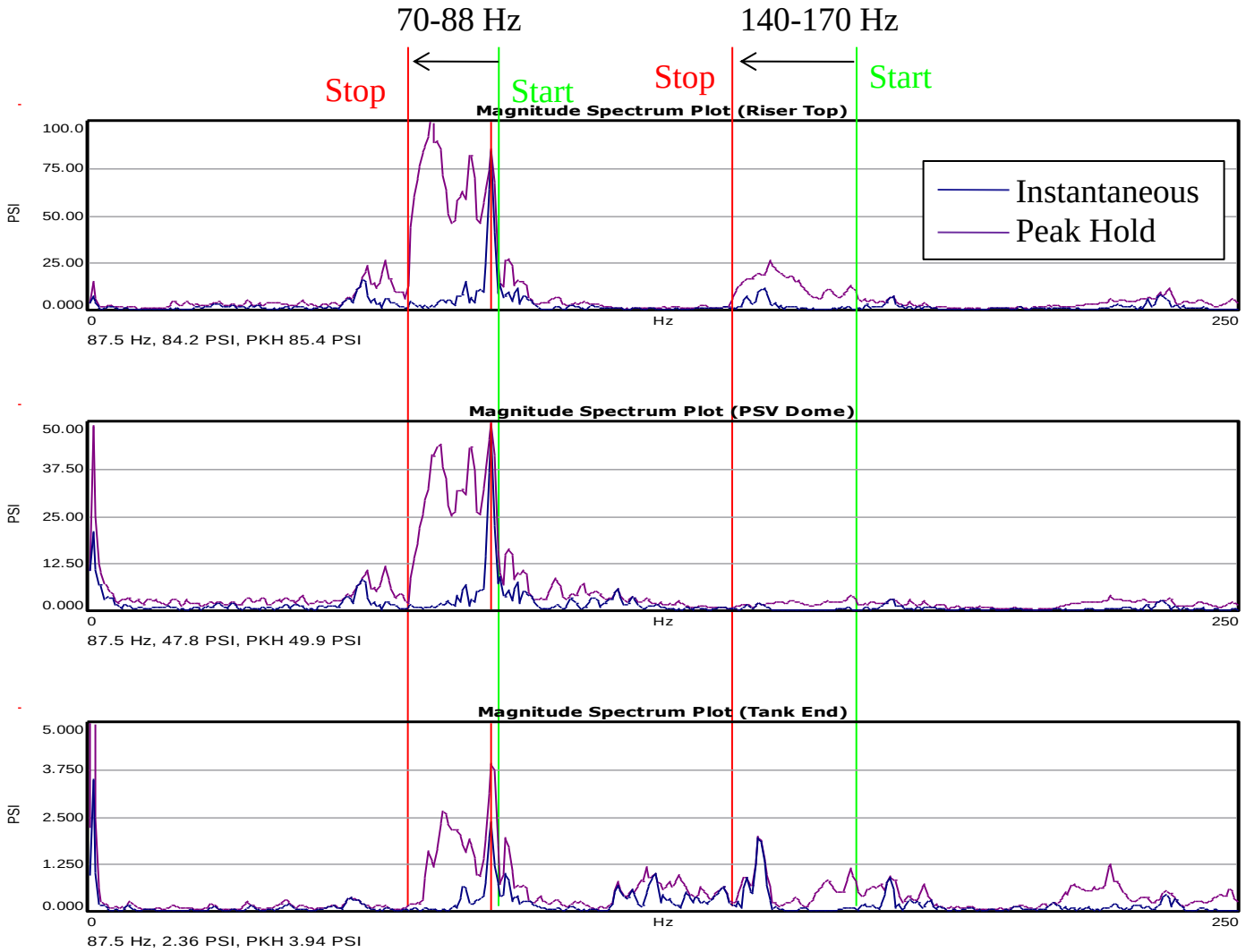


Blowdown Test Results – Pressures

Riser Top

PSV Dome

Tank End



Test Observations & Conclusions

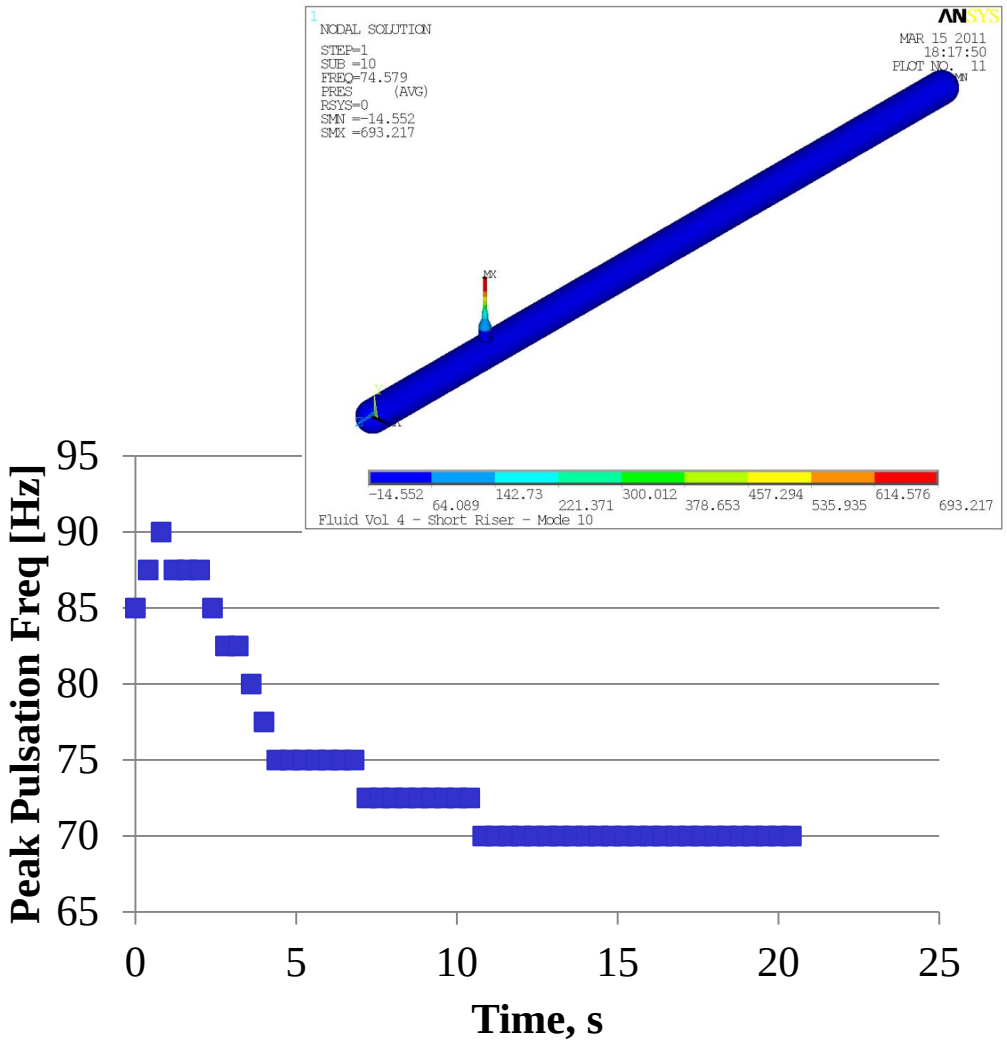
- Severe oscillations and pulsations occurred when testing with riser to PSV and with very low damping in system
  - No pulsations/oscillations when riser is removed
  - No pulsations/oscillations when testing with a “sticky” piston (cold o-rings and grease, piston rubbing on side walls)
- Pulsations occur at same frequency as piston oscillations
- Pulsations do not occur when piston oscillations not present
- Dome pressure fluctuates above sense line pressure of 300 psig, indicating this is not a pilot-driven instability
- Test results indicate that cause of oscillations/pulsations is a system instability where piston dynamics couple with riser acoustics.

Analytical Modeling

- Analyses performed to confirm root cause hypothesis
  - Acoustic analysis of test header and riser
  - Dynamic analysis of PSV piston
- Predictive modeling for new/redesigned systems
  - Separate acoustic and PSV dynamic analyses
  - Coupled model

Test Header Acoustic Analysis

- 3D Acoustic analysis performed in ANSYS
- Results show that first quarter-wave mode of riser has a natural frequency of 74.6 Hz
- Peak pulsation frequency from test locks into 75 Hz initially

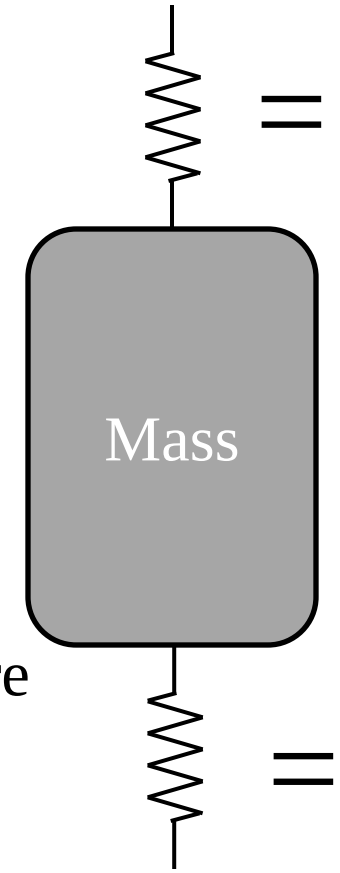


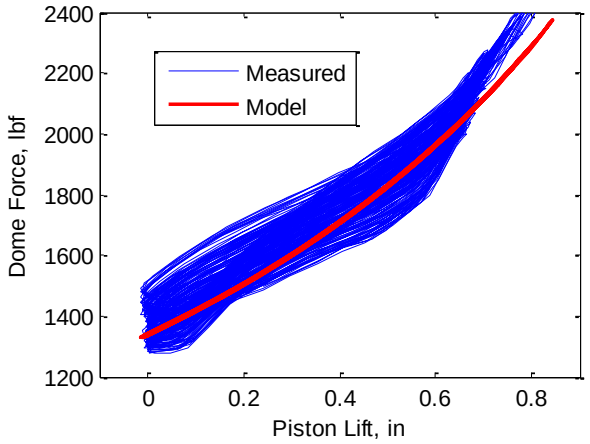
PSV Piston Dynamic Analysis

- Piston mass effectively supported by two "springs"
  - Gas spring from trapped gas in dome (easy to predict)

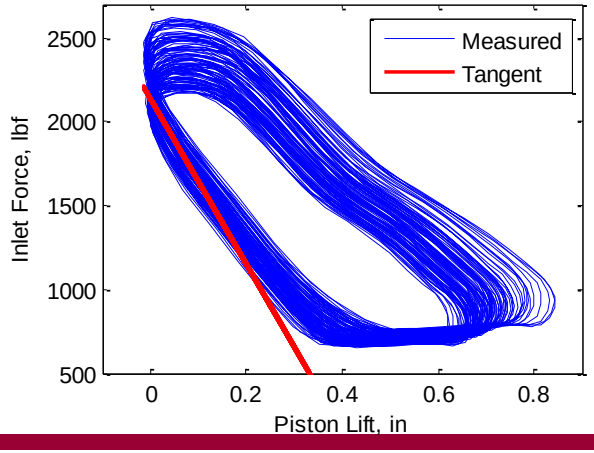
$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

  - Effective stiffness on sealing face due to pressure pulsations acting on effective force area (difficult to predict)





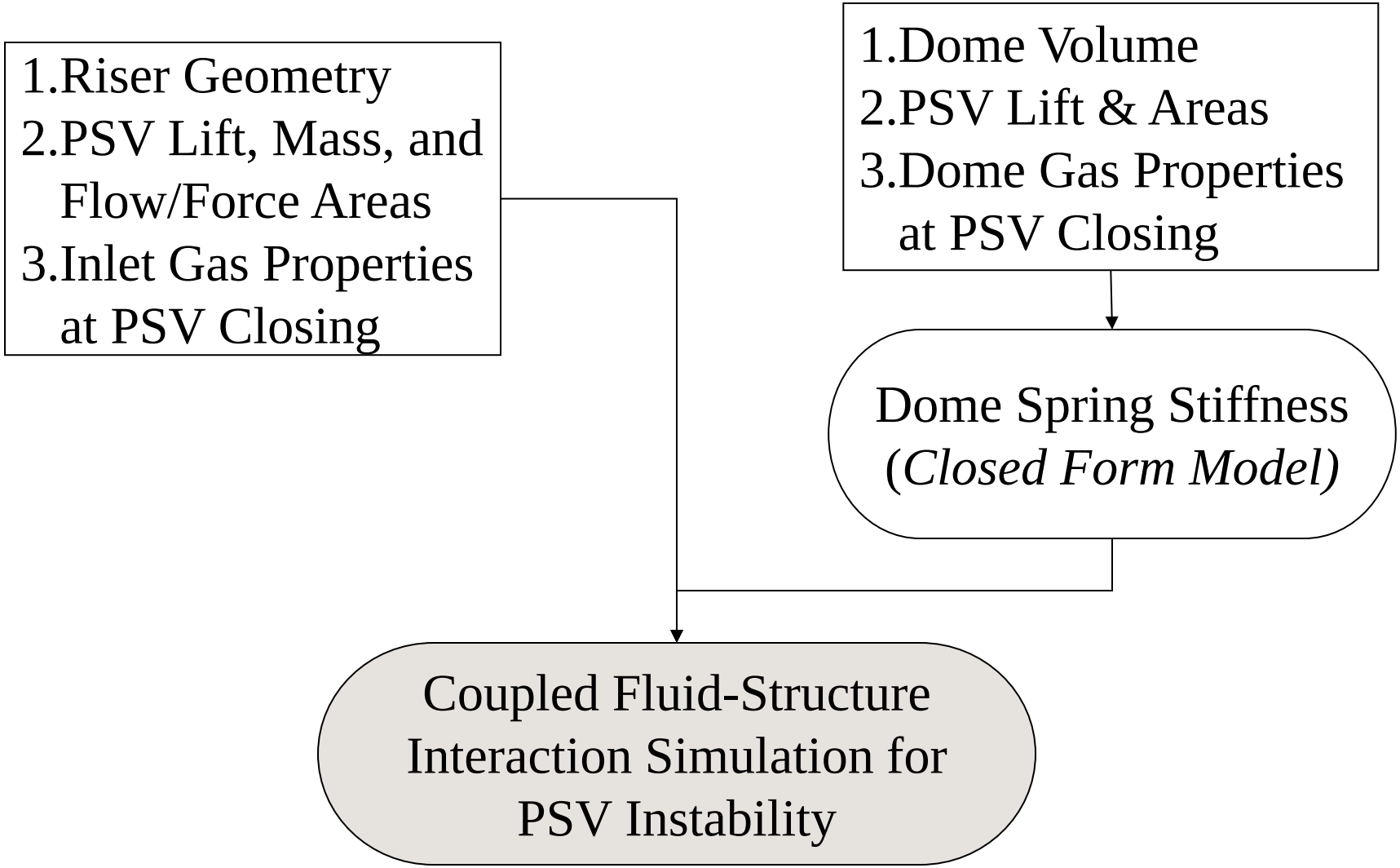
$$\sqrt{\frac{m}{k_1+k_2}} = 73.4 \text{ Hz}$$



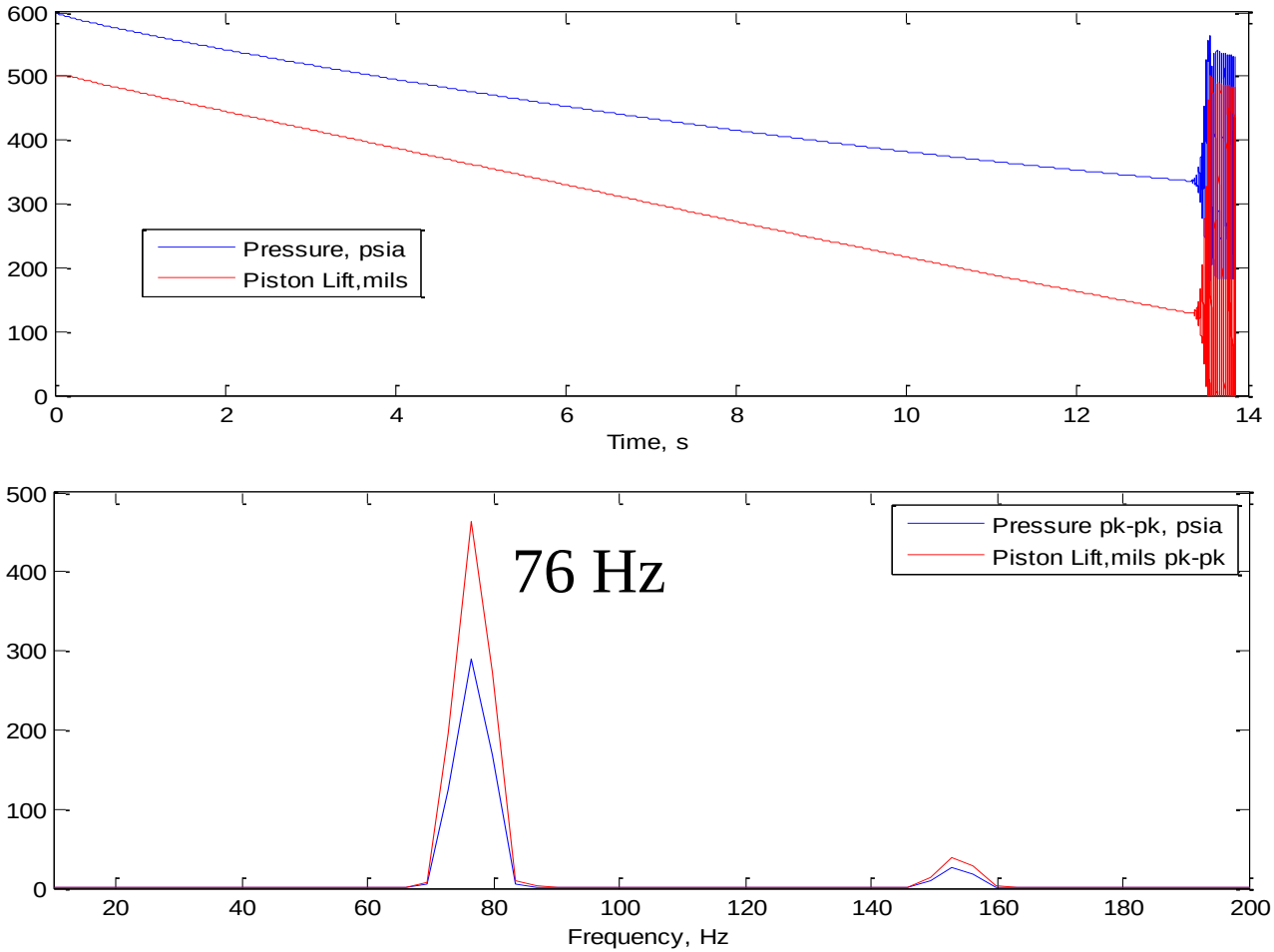
Predicting PSV Instability

- Prediction of the PSV instability requires several elements, some difficult to obtain
  - Prediction of riser acoustics (straightforward)
  - Prediction of gas spring stiffness in dome (straightforward)
  - Prediction of inlet stiffness is difficult since it requires knowledge of pulsation amplitude, phasing with respect to piston motion, and valve effective force area curve.
- Solution is to use coupled fluid-structure dynamics code
  - 1-D Navier-Stokes model with wall friction and viscous losses, typically used for reciprocating compressor pulsation studies. Accurately predicts pulsation amplitudes.
  - Incorporated PSV dynamic model into code

Fluid-Structure Interaction Analysis



PSV FSI Simulation Results



Note: Simulation results predict onset of instability near closing at same frequency observed in test.

Conclusions

- A new acoustic instability for pilot-operated PSVs has been identified, where PSV piston dynamics couple with inlet piping acoustics
- This instability can damage sealing surfaces in the valve and cause undesired system depressurization
- The instability was identified using separate acoustic and dynamic models for the PSV as well as a 1D fluid-structure interaction model
- The fluid-structure interaction approach is recommended for analyzing new applications since it accurately captures pulsation amplitude and phasing